

Concentrations of Trace Metals and other Constituents in Springs on the Double O Unit, Malheur NWR, Oregon.

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Date: June 26, 2013

Introduction

The Malheur NWR, established in 1908 and currently 187,757 acres in size, is the largest national wildlife refuge managed as waterfowl production and migration habitat in the West. There are a number of threats to the refuge that impede management actions to improve or enhance waterfowl habitat, including poor water quality and invasive species such as common carp (*Cyprinus carpio*). Carp were first observed in Malheur Lake in the 1950s and have subsequently spread to many other areas on the refuge. Carp have a number of deleterious effects on aquatic habitat (see Ivey et al. 1998 for review). They destroy aquatic vegetation and their foraging habits, spawning, and feeding habits increase water turbidity which decreases macrophyte and invertebrate production and reduces waterfowl food supplies. In addition, carp directly compete with waterfowl and waterbirds for aquatic invertebrates. Efforts to control carp in the lake and throughout the refuge have met with limited success. The refuge Comprehensive Conservation Plan (CCP) has identified poor aquatic health as the biggest issue the refuge is facing and has identified common carp as the largest contributor to degrading aquatic habitat.

The Double O unit is a management unit of the refuge that has a low carp population compared to other areas of the refuge and it may be feasible to exclude or control carp on the unit. For this reason, some conservation partners and CCP collaborators have advocated prioritizing habitat restoration efforts in this management unit. However, refuge staff have observed that while there appears to be few carp in this unit (particularly in some of the springs) there are also few invertebrates or submergent plants in these springs, and waterfowl and waterbird numbers are low. As a result, there may be factors other than carp that are limiting waterfowl productivity in this management unit.

The response of two different springs following a carp removal provides some evidence of this concern. In 2011-12, refuge staff successfully removed over 90% of adult carp from two springs: Barnyard Springs on the Double O unit and Sodhouse Springs near the refuge Headquarters. Prior to the removal, carp numbers and biomass were high whereas productivity and bird use were low in both areas. The response to carp removal was strikingly different between these two areas. In the absence of carp, Sodhouse Springs responded almost immediately with luxuriant growth of submergent vegetation, including sago pondweed production and abundant aquatic invertebrates. Waterfowl and other waterbird use of Sodhouse Springs has been very high since carp were removed. In contrast, Barnyard Springs on the Double O unit had almost no response in submergent vegetation or aquatic invertebrate production following carp removal. Barnyard Springs continues to have very low bird use and carp numbers near the source of the springs, although both waterbird use and carp appear to increase in areas downstream of the springs. If other factors besides carp limit waterfowl productivity in the springs on the Double O unit, then management options and feasibility of success for habitat restoration on this unit may also be limited.

The objective of this investigation was to determine if one or more trace elements are present at concentrations high enough to limit productivity in some springs on the Double O unit. Arsenic is of particular interest since elevated arsenic concentrations are common in springs and groundwater in the Great Basin http://nationalatlas.gov/articles/water/a_arsenic.html. High concentrations of arsenic or

some other trace element concentrations could directly impact one or more life stages of carp, or it could indirectly impact carp by limiting their food base.

Methods

Water quality samples were collected from springs in the Double O area and Sodhouse Spring, near the refuge headquarters. The Google Earth images at the end of the report indicate the location of the sample sites. The Sodhouse Springs was assumed to represent background conditions and was sampled for reference. Water samples were collected on 9/18/12 and 9/20/12. Table 1 and the attached maps show the numbers, names, locations, and collection date and time of the sampling sites. Samples were collected with a DH81 sampler with an extension rod from a Kayak pod. Each sample station was represented by 3L of water collected in nine increments. Each increment was collected in an integrated fashion by dipping the rod and 1L- plastic sample bottle slowly from surface to bottom (without disturbing the sediment), filling one-third of the sample bottle (i.e., one increment), at three separate locations, spaced no more than 10 m apart, to obtain a 1-liter sample. The 1-L sample was then poured into a 3-L plastic jug. The 1L- bottle was then filled in the same manner two more times at nearby locations, thereby obtaining 3L of water to represent one integrated sample. The 3L bottle was brought to shore, shaken, and emptied into a 500 ml acidified sample bottle (in thirds, re-shaking the 3-L bottle between each third). All sample collecting equipment was washed between samples with a dilute solution of Dawn detergent, followed by tap water, followed by 5% HCL solution, followed by DI water.

On 9/18/2012, field water quality parameters (water temperature, specific conductivity, dissolved O₂, pH) were collected at each site concurrent with trace element water sample collection with a Hydrolab® Datasonde3® multiparameter water quality instrument (multiprobe) . The multiprobe was not available on 9/20/2012. The multiprobe was calibrated on-site prior to deployment.

Table 1. Sample numbers, names, locations, and collection dates of samples collected in the study.

Sample No.	Site Name	Lat	Long	Collection Date/Time
M01	Sodhouse Pond	43.26632	-118.84441	Sample lost
M02	Sodhouse Pond outflow	43.26755	-118.84326	9/18/12 13:00 PST
M03	Barnyard Spring	43.27619	-119.31006	9/18/12 14:45 PST
M03-2	Barnyard Spring (duplicate sample)	43.27619	-119.31006	9/18/12 14:50 PST
M04	Barnyard Spring 2	43.27339	-119.30777	9/18/12 15:45 PST
M05	Barnyard Spring 3	43.27190	-119.30693	9/18/12 16:00 PST
M06	Hibbard Spring source	43.27333	-119.33055	9/18/12 17:25 PST
M07	Hibbard Spring outflow	43.28014	-119.31987	9/18/12 17:50 PST
M08	Hughnet Creek outflow	43.25482	-119.24760	9/20/20 09:30 PST
M09	Double O Springs outflow	43.28430	-119.31447	9/20/20 10:00 PST

All samples were labeled, preserved with nitric acid, stored at 4°C prior to shipping to one of the water quality contract labs identified by the Analytical Control Facility (ACF) of the USFWS. None of the samples were filtered. All samples were analyzed for 22 constituents using an inductively coupled plasmaspectroscopy (ICP) scan (using EPA method 200.8). Names and chemical symbols for the 22 constituents are shown in Table 2.

Sample concentrations were compared with established water quality criteria and information from other literature studies to assess potential impacts to species and habitats. Two government sources of water quality criteria and guidelines were used to evaluate sample concentrations: the U.S. Environmental Protection Agency (EPA) National Water Quality Criteria for Aquatic Life (<http://water.epa.gov/scitech/swguidance/standards/criteria/current/index.cfm#altable> accessed 5/15/13) and the Canadian water quality guidelines for the protection of aquatic life (Canadian Council of Ministers of the Environment, 2007). The criteria from each of these sources for each constituent, where available, are given along with the sample results. The current national criteria developed by the U.S. Environmental Protection Agency (EPA) are used for comparison purposes rather than state water quality standards. Although Oregon has adopted numeric water quality criteria for protection of aquatic life, a recent approval/disapproval action by EPA has created some uncertainty regarding the protectiveness of these state criteria for Oregon aquatic life.

Table 2. Names and Symbols of Chemical Analyzed

Al	Aluminum	Co	Cobalt	Pb	Lead
As	Arsenic	Cu	Copper	Se	Selenium
B	Boron	Fe	Iron	Sr	Strontium
Ba	Barium	Hg	Mercury	Tl	Thallium
Be	Beryllium	Mg	Magnesium	V	Vanadium
Ca	Calcium	Mn	Manganese	Zn	Zinc
Cd	Cadmium	Mo	Molybdenum		
Cr	Chromium	Na	Sodium		

Results and Discussion

Results for field water quality parameters are shown below in Table 3. The water temperature and pH of Sodhouse Springs differs from the other springs in the Double O area. Springs in the Double O area are all warmer and higher in pH compared to Sodhouse Springs, which indicates that these springs are mildly geothermic and are sourced differently. The specific conductivity of sites M04 and M05 is much higher than the other sites, indicating higher dissolved ion concentrations at these sites. This may be due to different source waters for these sites or it may be because these sites are hydrologically isolated from the other springs. The conductivity and dissolved oxygen values at all the sites are within the range of values reported by Rinella and Schuler (1992) for springs and lakes at Malheur NWR. The pH measured at all the sites is at the upper end of the range of values reported in this same study for springs and lakes at Malheur NWR.

Results for constituents in the water samples are presented by site in Table 4. The maximum and minimum values for each constituent are highlighted in the table as well. Concentrations for six of the constituents (beryllium, cadmium, mercury, lead, selenium, thallium) were very low or non-detectable at all the sites. Rinella and Schuler (1992) reported similar results for cadmium, mercury, and selenium (beryllium, lead, and thallium were not analyzed in their study).

Table 3. Field water quality parameters for springs, Malheur NWR, September 2012.

Site Name	Temperature (C)	Conductivity (mS/cm)	Dissolved O ₂ (mg/L)	Dissolved O ₂ (% saturation)	pH
Sodhouse Pond	12.21	3.71	6.0	55	7.82
Sodhouse Pond outflow	13.09	3.74	7.8	73	8.07
Barnyard Spring	22.46	3.39	6.54	75	8.28
Barnyard Spring 2	25.06	29.9	7.30	107	8.96
Barnyard Spring 3	21.74	17.0	8.02	98	8.53
Hibbard Spring source	22.9	3.11	9.14	108	8.82
Hibbard Spring source (duplicate measurement)	22.25	3.15	11.86	136	9.09
Hibbard Spring outflow	21.8	3.12	12.83	140	9.19
Hughnet Creek outflow	NA	NA	NA	NA	NA
Double O Springs outflow	NA	NA	NA	NA	NA

Sixteen constituents had measurable concentrations at some or all of the sites. For constituents with detectable concentrations, samples from Barnyard Springs 2 and 3 (Sample Sites M04 and M05) consistently had the highest concentrations compared to the other sites. The two spring sites had concentrations of aluminum, boron, barium, copper, iron magnesium, manganese, sodium, nickel, strontium that were about an order of magnitude greater than the other sites. The concentration of iron at sites M04 and M05 was 0.688 and 1.31 mg/L, whereas it was below the detection limit of 0.05 mg/L at all the other sites, except for Sodhouse Spring, where it was 0.058 mg/L, just above the detection limit. The concentration of aluminum at sites M04 and M05 was 0.859 and 1.61 mg/L, whereas it was below the detection limit of 0.1 mg/L at all the other sites. The Canadian Guidelines for Protection of Aquatic Life are 0.3 mg/L for iron and 0.1 mg/L for waters at pH>6.5 for aluminum (Canadian Council of Ministers of the Environment, 2007). The USEPA Water Quality Criteria for Aquatic life are 1.0 mg/L for Fe and 0.3 mg/L for Al. Concentrations for both of these constituents at these sites are at or above the guidelines and criteria. In contrast, calcium concentration was about equal at M04, M05, and Sodhouse Spring, and was only slightly higher at these three sites than the remaining sites.

Arsenic was measured above the detection limit (0.0005 mg/L) in all samples, although there was a wide range of concentrations among the sites. The Sodhouse Spring sample had the lowest arsenic concentration of all the samples (0.0049 mg/L) and the highest arsenic concentrations were from M04 and M05. Concentrations at M04 and M05 were 0.0541 mg/L and 0.0395 mg/L, respectively, which is about an order of magnitude higher than the sample from Sodhouse Spring. Arsenic concentration in Barnyard Spring (M03 and M03-2) were 0.0125 and 0.0127 mg/L (these were duplicate samples from the same site), which is about 3 times as high as Sodhouse Spring concentrations. Arsenic concentrations in all the other samples were intermediate between Barnyard Spring and Sodhouse Spring.

Arsenic occurs naturally in springs and groundwater in areas around Malheur NWR and elsewhere in the Great Basin. Several other studies and sampling efforts have reported high arsenic concentrations in or near the refuge. In 1988, water quality at Malheur NWR was evaluated extensively during the U.S. Department of Interior's drainwater irrigation program, and arsenic and other trace elements were evaluated (Rinella and Schuler, 1992). Sampling included springs in the Double O Unit, as well as many other sites throughout the refuge. Two springs were sampled in the Double O unit: the Double O Cold Spring (a small, colder spring with a flow of 0.5-1.0 cfs) and the combined outflow from Barnyard, Hibbard, and Basque springs (samples collected about 2 miles downstream on the channel with the combined spring outflow). The Double O Cold Spring had an arsenic concentration of 0.008 and 0.009 mg/L (based on 3 samples), which is which is relatively low. The colder temperature of this spring suggests a shallower, more local source of groundwater supplying the spring. The second site sampled, from the combined outflow of the Barnyard, Hibbard, and Basque springs, had an arsenic concentration of 0.047 mg/L (n=1), similar to the values reported in this investigation.

Elsewhere around the refuge, Rinella and Schuler (1992) reported arsenic concentrations that were generally low (0.001-0.002 mg/L or less), except for the lakes. Malheur Lake had arsenic concentrations of 0.055 and 0.062 mg/L, the Narrows had an arsenic concentration of 0.078 mg/L, and Harney Lake had arsenic concentrations of 0.250 and 0.330 mg/L. The authors state that concentrations measured "in both lakes could potentially inhibit survival and production of invertebrates..."

Earlier sampling from other studies evaluated by Rinella and Schuler (1992) indicated a range of much lower arsenic concentrations in both lakes: 0.008-0.015 mg/L from samples collected in Malheur Lake in 1972-73, 1984, and 1985 and 0.120-0.140 mg/L in Harney Lake in 1984 and 1985. The reported concentrations from the 1988 sampling were about 2-3x the reported concentrations from 1984 to 1985, probably because the lakes had higher water levels and therefore, arsenic would have been more diluted in 1984 and 1985. This suggests that the arsenic exposure of organisms in both lakes (but particularly in Malheur Lake) is going to be a function of lake levels and inflows. Evaporative concentration and variable stream inflows can cause large fluctuations in the arsenic concentrations in the lakes. Concentrations in the spring heads, on the other hand, aren't expected to vary as much considering the consistent inflow and volume.

Another USGS study (Fuste and McKenzie, 1987) on the Malheur River, east of the refuge, found elevated concentrations of arsenic in a particular reach of the river, which they attributed to thermal springs along that reach (although they did not sample those springs). Fuste and McKenzie (1987) also reported results from groundwater samples, including a well located south of Malheur Lake and east of the refuge headquarters. Concentrations in the well were 0.090 mg/L, indicating naturally-high arsenic in groundwater in this area.

Arsenic is extremely toxic to humans and aquatic biota and is used broadly as sodium arsenite to control submerged aquatic vegetation in freshwater lakes and ponds. Currently, there are no U.S. water quality criteria for protection of aquatic life for arsenic. Rinella and Schuler (1992) state that arsenic can affect aquatic plants at concentrations as low as 0.048 mg/L whereas acute toxicity can occur to freshwater aquatic organisms at 0.850 mg/L. The Canadian Council of Ministers of the Environment (2001) states that the green algae, *Scenedesmus obliquus*, had a 14-day EC₅₀ of 0.050 mg /L. The Canadian water quality guideline for protection of aquatic life is 0.005 mg/L (Canadian Council of Ministers of the Environment, 2007). The USEPA criteria is much higher, by comparison: 0.150 mg/L.

Aquatic plants are more sensitive to arsenic than fish and invertebrates. Birge et al. (1979) reported a 28-day LC_{50} of 0.55 mg/L for rainbow trout (*O. mykiss*), which is an order of magnitude greater than what was observed at M04 and M05. The lowest estimates of arsenic toxicity for plants ranged from a 14-day EC_{50} (growth) of 0.05 mg/L for *Scenedesmus obliquus* (Vocke et al. 1980), two EC_{50} s (growth) of 0.075 mg/L for *Melosira granulata* and *Ochromonas vallesiaca* (Planas and Healey 1978), to a 20-day VSUE (very severe unfavorable effect) of 0.96 mg/L for *S. quadricus* (Fargasova 1993).

The arsenic concentrations observed at all the sites were greater than the concentration of 0.005 mg/L given in the Canadian Guidelines for Protection of Aquatic Life (Canadian Council of Ministers of the Environment, 2007). But this criterion is definitely low compared to the values from the other toxicity studies for arsenic. It is more conservative than the USEPA water quality criteria of 0.150 mg/L. The maximum arsenic concentrations observed in this investigation, at M04 and M05, are well above the Canadian guideline and are close to the values reported as affecting aquatic plants. The fact that Rinella and Schuler (1992) reported an arsenic concentration of 0.047 mg/L two miles downstream of Barnyard Spring in the spring outflow creek, suggests that the high concentrations at these two sites are representative of source concentrations along the outflow stream and not just a result of hydrologic isolation at the sites themselves.

Aluminum at sites M04 and M05 is also above the recommended concentrations for protection of aquatic life (0.100 mg/L at $pH > 6.5$, from the Canadian Council of Ministers of the Environment, 2003 and 0.087 mg/L from USEPA). All the other sites had aluminum concentrations below the detection limit of 0.1 mg/L. The concentrations at M04 and M05 are slightly elevated over normal background concentrations. Ambient levels of aluminum in water at circumneutral pH are usually < 1 mg/L and more typically around 0.500 mg/L (Canadian Council of Ministers of the Environment, 2003). This suggests that the levels in the guidelines and criteria are close to ambient levels.

The toxicity of aluminum varies widely and is dependent on pH as well as the concentration of dissolved organic carbon, phosphorus, calcium, and iron. Fish and amphibians tend to be highly sensitive to aluminum concentrations but aquatic plants less so. Key factors in aluminum sensitivity for fish are species, life stage, and form of aluminum. Several studies have reported that juveniles tend to be the most sensitive life stage while embryos are the least sensitive in fish (Baker and Schofield 1982; Rosseland et al. 1992; Roy 1998). Fish species have been found to be equally sensitive to three forms of aqueous monomeric Al (i.e., Al^{3+} , $Al(OH)^{2+}$, and $Al(OH)_2^+$) (Sparling and Lowe 1996).

Nickel is toxic to carp (Blaylock and Frank, 1979) but levels of toxicity are several orders of magnitude above what was observed here, even in the sites with the highest concentrations. The recommended concentrations for protection of aquatic life are an order of magnitude greater than the concentrations observed at most of the sites in this investigation (Table 4).

Boron concentrations were above the detection limit at all sites, with the highest concentrations observed at M04 and M05 (3.80 and 1.86 mg/L, respectively). Mean boron concentration in freshwaters in the U.S. is 0.1 mg/L, although groundwater can have substantially higher concentrations (USEPA, 1986). The boron concentrations observed in this investigation are similar to those reported by Rinella and Schuler (1992) for springs on the refuge. Those authors suggested that boron concentrations may be a concern on the Refuge. Sources of boron in the area are believed to be from naturally-occurring boron-rich deposits in the area.

Both fish and invertebrates appear to have wide ranges in sensitivity to boron among species (Soucek et al., 2011). The lowest effect concentration (LOEC) for a fish species is the 28-day LOEC (mortality at hatching) of 1.34 mg/L for rainbow trout (Black et al., 1993). Currently, there are no U.S. water quality criteria for protection of aquatic life for boron. The concentrations observed here exceed the recommended level of 1.2 mg/L for protection of aquatic life (Canadian Council of Ministers of the Environment, 2009). California has a water quality criteria document published for the California State Water Quality Control Board that provided evidence that waters > 1 mg/L boron could be harmful to irrigated crops. Soucek et al. (2011) concluded that the current state water quality standard for Illinois (also 1.0 mg/L) was adequate and likely conservative. As a result, it is inconclusive whether or not the high boron concentrations observed at M04 and M05 are of concern.

Conclusions and Management Recommendations

Barnyard Spring 2 and Barnyard Spring 3 sites (M04 and M05) consistently had the highest concentrations of all the sites for any constituent evaluated in this investigation. The two sites had concentrations of aluminum, boron, barium, copper, iron magnesium, manganese, sodium, nickel, and strontium that were about an order of magnitude greater than the other sites. Specific conductivity, a measure of dissolved ion concentrations, also was highest at these two sites.

The concentrations of arsenic were highest in the Barnyard Springs area, sites M04 and M05, where concentrations were 0.054 and 0.40 mg/L, respectively. However, arsenic concentrations at all sites were above the Canadian Water Quality Guidelines for Protection of Aquatic Life (0.005 mg/L), with the exception of the concentration at Sodhouse Springs. This concentration is quite conservative compared with the USEPA criteria of 0.150 mg/L. The concentrations in the Barnyard Springs area, sites M04 and M05, were about an order of magnitude greater than the Canadian guideline and are within the range known to have deleterious effects to aquatic plants.

Concentrations of other constituents are elevated above water quality guidelines as well at some of the sites. Aluminum and boron are both above the Canadian Water Quality Guidelines for Protection of Aquatic Life (Canadian Council of Ministers of the Environment, 2007) at M04 and M05 but not at the Barnyard Spring site (M03 and M03-2) or at the other sites.

The water quality sampling results provide evidence that arsenic could be limiting productivity in this area, although the evidence is not conclusive. Of the 22 constituents analyzed here, arsenic seems like the most probable constituent limiting productivity in the Barnyard Springs area.

The study indicates that refuge springs with higher arsenic levels (geothermal sources) should receive lower priority to conduct carp control for habitat restoration given the expense of rotenone treatments. Restoration efforts should be focused on those springs that have a higher likelihood of a favorable habitat response after treatment. That said, certain springs may need to be treated for carp regardless of arsenic levels because they possibly serve as source populations to infest other springs with quality habitat.

Acknowledgments

The USFWS Division of Environmental Quality provided funding for the sample analyses in this study. I would like to thank Jeremy Buck and Elizabeth Materna for helping with field water quality measurements and sample collection and for a fine day in the field. They, along with Kevin Kilbride, also provided reviews and comments on this report.

Literature Cited

Baker, J.P., and C.L. Schofield. 1982. Aluminum toxicity to fish in acidic waters. *Water Air Soil Pollut.* 18: 289-309.

Birge, W.J., J.E. Hudson, J.A. Black, and A.G. Westerman. 1979. Embryo-larval bioassays on inorganic coal elements and in situ biomonitoring of coal-waste effluents. In: *Surface mining and fish/wildlife needs in the eastern United States*, D.E. Samuel, J.R. Stauffer, C.H. Hocutt, and W.T. Mason Jr., eds., pp. 97-104. Fish and Wildlife Service, Office of Biological Services. FWS/OBS-78/81. U.S. Government Printing Office, Washington, DC.

Blaylock, B.G. and M.L. Frank. 1979. A comparison of the toxicity of nickel to the developing eggs and larvae of carp (*Cyprinus carpio*). *Bull. Environm. Contam. Toxicol.* 21:604-611.

Canadian Council of Ministers of the Environment, 2001. Canadian water quality guidelines for the protection of aquatic life: Arsenic. In: *Canadian environmental quality guidelines, 1999*, Canadian Council of Ministers of the Environment, Winnipeg, Canada.

Canadian Council of Ministers of the Environment, 2003. Canadian water quality guidelines for the protection of aquatic life: Aluminum. In: *Canadian environmental quality guidelines, 1999*, Canadian Council of Ministers of the Environment, Winnipeg, Canada.

Canadian Council of Ministers of the Environment, 2007. Canadian water quality guidelines for the protection of aquatic life, Summary table, Updated December 2007. In: *Canadian environmental quality guidelines, 1999*, Canadian Council of Ministers of the Environment, Winnipeg, Canada.

Canadian Council of Ministers of the Environment, 2009. Canadian water quality guidelines for the protection of aquatic life: Boron. In: *Canadian environmental quality guidelines, 2009*, Canadian Council of Ministers of the Environment, Winnipeg, Canada.

Fargasova, A. 1993. Effect of five toxic metals on the alga *Scenedesmus quadricus*. *Biologia (Bratislava)* 48(3):301-304.

Ivey, G.L., J.E. Cornely, and B.D. Ehlers. 1998. Carp impacts on waterfowl at Malheur National Wildlife Refuge. *Trans. 63rd No. Am. Wildl. And Natur. Resour. Conf.*

Planas, D., and F.P. Healey. 1978. Effects of arsenate on growth and phosphorus metabolism of phytoplankton. *J. Phycol.* 14:337-341.

Soucek, D.J., A. Dickinson, and B.T. Koch. 2011. Acute and chronic toxicity of boron to a variety of freshwater organisms. *Environm. Toxicol. And Contam.* 30(8):1906-1914.

Sparling, D.W., and T.P. Lowe. 1996. *Reviews of Environmental Contamination and Toxicology*. Volume 145. Springer-Verlag, New York.

Rinella, F.A. and C.A. Schuler. 1992. Reconnaissance investigation of water quality, bottom sediment, and biota associated with irrigation drainage in the Malheur National Wildlife Refuge, Harney County, Oregon, 1988-89. U.S. Geological Survey Water Resources Investigations Report 91-4085.

Rosseland, B.O., I.A. Blaker, A. Bulgar, F. Kroglund, A. Kvellstad, E. Lydersen, D.H. Oughton, B. Salbu, M. Staurnes, and R. Vogt. 1992. The mixing zone between limed and acidic river waters: complex aluminum chemistry and extreme toxicity for salmonids. *Environ. Pollut.* 78: 3-8.

Roy, R. 1998. The Chemistry, Bioaccumulation and Toxicity of Aluminum in the Aquatic Environment for the PSL2 Assessment of Aluminum Salts. Prepared for Environment Canada Chemicals Evaluation Branch by Robert Roy E.S.G. International, Guelph, Ontario.

USEPA, 1986. Quality criteria for water 1986. Environmental Protection Agency, Office of Water Regulations and Standards. Washington D.C. EPA 440/5-86-001.

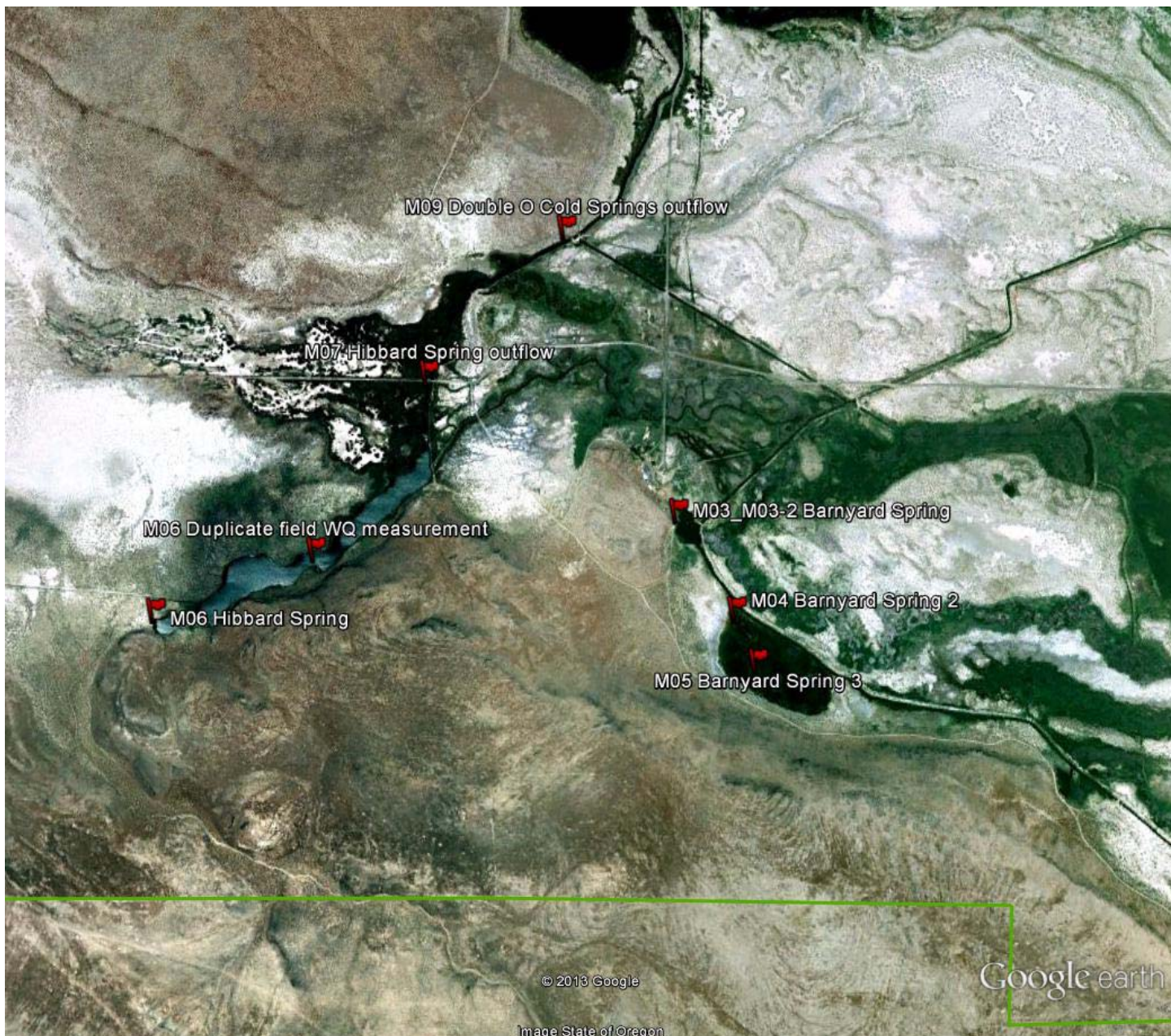
Vocke, R.W., K.L. Sears, J.J. O'Toole, and R.B. Wildman. 1980. Growth responses of selected freshwater algae to trace elements and scrubber ash slurry generated by coal-fired power plants. *Water Res.* 14:141-150.

Table 4. Concentrations (mg/L) at each site for all 22 constituents analyzed, along with values from the Canadian Water Quality Guidelines for Protection of Aquatic Life (Canadian Council of Ministers of the Environment, 2007), where available. Minimum and maximum values for each constituent are highlighted in blue and red font, respectively.

Site Name	Al	As	B	Ba	Be	Ca	Cd	Co	Cr	Cu	Fe
Sodhouse Pond outflow	BDL	0.0049	0.145	0.0011	BDL	20.0	BDL	BDL	BDL	0.002	0.058
Barnyard Spring	BDL	0.0125	0.350	0.0011	BDL	9.1	BDL	BDL	BDL	0.002	BDL
Barnyard Spring (duplicate)	BDL	0.0127	0.377	0.0012	BDL	9.7	BDL	BDL	BDL	0.001	BDL
Barnyard Spring 2	0.859	0.0541	3.800	0.0112	BDL	16.0	BDL	0.0005	0.002	0.011	0.688
Barnyard Spring 3	1.610	0.0395	1.860	0.0171	BDL	21.6	BDL	0.0013	0.003	0.009	1.310
Hibbard Spring source	BDL	0.0075	0.518	0.0034	BDL	11.3	BDL	BDL	0.002	BDL	BDL
Hibbard Spring outflow	BDL	0.0075	0.479	0.0032	BDL	11.3	BDL	BDL	0.001	0.001	BDL
Hughnet Creek outflow	BDL	0.0090	0.540	0.0049	BDL	11.9	BDL	BDL	0.002	BDL	BDL
Double O Cold Spring outflow	BDL	0.0078	0.483	0.0028	BDL	11.4	BDL	BDL	0.001	BDL	BDL
Canadian Guidelines	0.1 at pH>6.5	0.005	1.0	1.0	0.005	NA	0.01	NA	0.001-0.009	0.004	0.3
USEPA WQ Criteria	0.087	0.150	NA	NA	NA	NA	0.00025	NA	0.011	NA	1.0

Site Name	Hg	Mg	Mn	Mo	Na	Ni	Pb	Se	Sr	Tl	V	Zn
Sodhouse Pond outflow	<0.00005	11.80	0.0016	0.0032	28.8	0.0009	BDL	BDL	0.0972	BDL	0.013	0.019
Barnyard Spring	<0.00005	2.88	0.0008	0.0021	30.4	BDL	BDL	BDL	0.0465	BDL	0.011	0.014
Barnyard Spring (duplicate)	<0.00005	2.94	0.0007	0.0026	31.6	0.0006	BDL	BDL	0.0508	BDL	0.012	BDL
Barnyard Spring 2	<0.00005	24.40	0.0633	0.0059	564.0	0.0021	BDL	0.005	0.1480	BDL	0.013	0.017
Barnyard Spring 3	<0.00005	19.30	0.1590	0.0033	279.0	0.0036	BDL	BDL	0.1390	BDL	0.022	0.016
Hibbard Spring source	<0.00005	4.59	0.0014	0.0022	29.3	0.0008	BDL	BDL	0.0625	BDL	0.015	0.012
Hibbard Spring outflow	<0.00005	4.60	0.0019	0.0021	28.9	0.0009	BDL	BDL	0.0720	BDL	0.014	0.012
Hughnet Creek outflow	<0.00005	5.91	0.0020	0.0028	34.2	0.0006	BDL	BDL	0.0877	BDL	0.015	0.013
Double O Cold Spring outflow	<0.00005	4.50	0.0020	0.0021	29.1	0.0007	BDL	BDL	0.0632	BDL	0.013	0.014
Canadian Guidelines	0.026	NA	NA	0.073	NA	0.015	0.007	0.001	NA	0.0008	0.006	0.030
USEPA WQ Criteria	0.00077	NA	NA	NA	NA	0.052	0.0025	0.005	NA	NA	NA	0.120

BDL is below detection limit. Detection limits were 0.1 mg/L for Al; 0.0005 mg/L for Be, Cd, Hg, and Ni; 0.0002 mg/L for Co and Tl; 0.001 mg/L for Cu and Pb; 0.05 mg/L for Fe; 0.01 mg/L for Zn.



Google earth

miles 1
km 1





Google earth

miles 5
km 8





Google earth

miles 4
km 6

